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## Epoxy Resin Grout System for Solutions to Traditional Geotechnical Problems

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**SYNOPSIS:** Use of chemicals for foundation treatment and sealing of crack is of recent origin. The aim of this paper is to find time-viscosity and time-strength relationships of epoxy grout system for proper flow mechanism and strength interaction with rock collected from dam sites of India. The bonding mechanism of gel in the injected mass is explained with the help of Scanning electron microscopy and Infra-red spectroscopy. After trial field grouting the stratascopy has revealed better bonds of moist surface with flexibility to accomodate movement before bond or shear failure occurred and had lower volumetric shrinkage during curing.

### INTRODUCTION

Cement grouting is well recognised method available to the Civil engineering practice. Epoxy resin have often used for various problems in civil engineering works in India, during the last decades. The sealing of cracks (Koyna, 1968; Konar, 1971; Hirakund, 1976) in concrete structures, plugging of leaks in hydraulic structures and bonding of fresh concrete to hardened concrete are the main applications which are quite wide spread. The main traditional Geotechnical problem for foundations in jointed and fractured rocks is the low bearing power against the structural stresses. The recently innovated application of epoxy grouting of jointed and fractured rock for reducing mass permeability and increasing compressive and tensile strength of bed rock (Norad dam, 1968). For the last application, the correlation of initial rheology of epoxy grout and the interacted strength of set grout at joints are very essential.

This paper developes epoxy gel by interacting chemical compound derived from bis-phenol A with epichlorohydrin and catalyst or hardener consisting of amines and polyamides by conceptual approach along with conventional frame work approach. The aim is to find a suitable time-viscosity relationship of an injection mix which facilitates proper flow mechanism into rock joints or fissures or cracks of the fractured rocks. The microscopic examination helps putforth the interaction and bonding mechanism of grout in an injected mass. Rock strengthening of samples collected from the site near to Panam dam and Karjan dam site and one construction site near Chhuchapura of Gujarat, India, were accomplished by laboratory injection of epoxy grout which has provided greater strength and better penetration than could have been obtained with the use of portland cement grout. This advantage justifies the use of epoxy grout as against the use of cement grout.

### GEL FORMATION AND ITS MECHANISM

When catalyst or hardener is mixed with base resin, the formation of gel occurs in three sequential steps: (1) Formation of primary micro gel, (2) Formation of secondary micro gel, and (3) Formation of macro gel.

The reactivities of primary and secondary amine groups of hardener give a linear structure in the alkaline media due to a combination of exothermic heat of reaction, the temperature will rise in the vicinity of the resin molecules, resulting into reaction of secondary amine group, causing the increase of vacant places between the molecules reflecting increase of fluidity. The growth of nuclei continue until the reactive polymer molecules can diffuse to the reactive sites of the nuclei. During this process several new nuclei are also developed resembling the crystallization process.

The primary micro gel and growing nuclei begine to interact each other and give rise to new nuclei for the secondary micro gel increasing viscosity of the system.

At a critical solid concentration the secondary micro gel pack together very suddenly and the experimental gel point is observed (Fig.1).

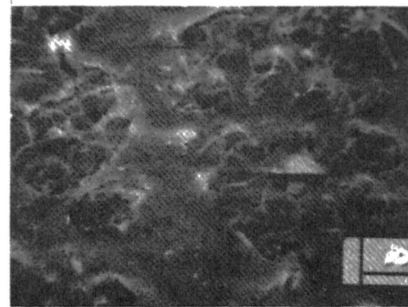


Fig.1 Micrograph

50 μm

The higher cross linked density reflects in better coherence by bonding with dry and wet surfaces of mass to be interacted.

Infra-red spectroscopy of a unit cell of set mass gives characteristics bonds of methylene or methylene, and phenyl groups at 1440 and 1505  $\text{cm}^{-1}$  bends.

#### DEVELOPMENT OF GROUT MIX

As per the requirement of resultant gellified mass, either rigid, elastic or elastoplastic, the unit cell is cultivated employing conceptual frame work approach by proportionating resin, hardener and water components. From the unit cell a repeatable unit in the polymer structure is developed.

Gel time increases upto resin: hardener ratio of two, thereafter it drops. The addition of water effectively reduces the gel time (Fig.2)

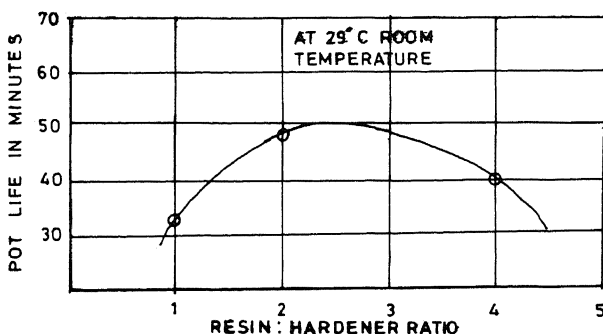


Fig.2 Variation of pot life

Strength of raw gel is controlled by resin to hardener ratio, while trace amount of water optimizes the viscosity of the grout system in addition to lowering the heat of reaction. While interacting with rock, it acts as a wetting, lubricating and spreading agent of grout.

#### RHEOLOGICAL ASPECTS

Rheological analysis of developed grout system are carried out by time-viscosity study employing Brookfield synchroretic viscometer, U.S.A., and newly developed Orifice type glass cone viscometer. It seems from time-viscosity curve (Fig.3),

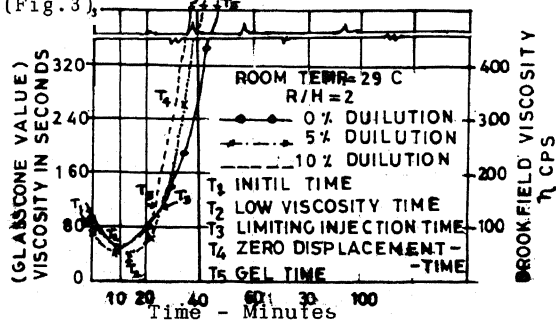


Fig.3 Time - Viscosity Relationship

that initial viscosity drops to 50 per cent upto 12 minutes, thereafter increases to semi-viscous limiting injection stage transforming suddenly to gel stage at about 35 minutes. The time-viscosity plot suggest the proper injection time of 12 minutes and limiting injection time of 24 minutes after mixing. Shear modulus data as obtained from the wave velocity pattern of pulse transmission through gellified mass interprets that gel mass which was visco-elastic before gel time transforms to elastic at gel time.

#### STRENGTH ASPECTS

Triaxial, unconfined compressive strength and tensile strength at 1 hour, 14 days and 21 days are increased upto resin: hardener ratio two, which tends to decrease thereafter. Unconfined compressive strength as measured on 200 T capacity 'VEB-Werkstoffprüfmaschinen', for resin: hardener ratio of two, gives 662.8  $\text{kg/cm}^2$ , 775.36  $\text{kg/cm}^2$ , 800.12  $\text{kg/cm}^2$  at 1 hour, 14 days and 21 days curing time (Fig.4).

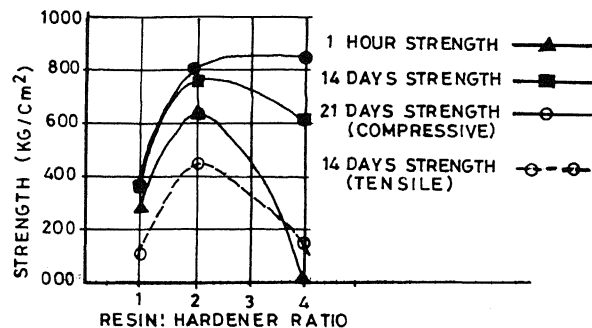


Fig. 4 Compressive and Tensile strength.

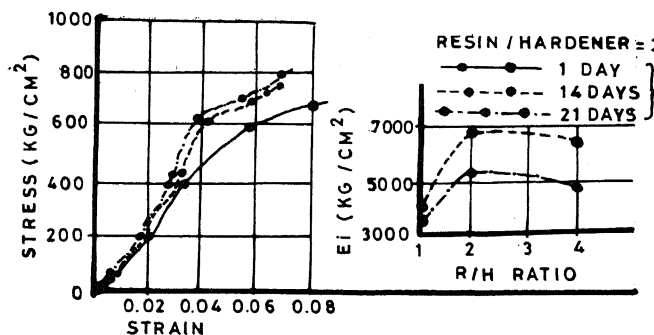


Fig.5 Stress-strain - Time relation of raw gel

Stress-strain curve (Fig.5) indicates that peak stress increases with increase of curing time reverting strength-time relationship of epoxy set mass as strongly time dependent. Two categories basically identified, mainly time dependent linear elastic and time dependent non-linear

elesto-plastic leading to brittle failure. Increase of resin: hardener ratio increases the brittleness in the system. As resin: hardener ratio increases to two, initial tangent modulus drops. Per cent failure strain decreases initially with increase of curing period upto 14 days and tends to remain constant thereafter. Trace amount of water in resin-hardener system makes the set mass elesto-plastic rather than brittle plastic exhibiting bulging at failures. Stress-strain curve of raw grout portrayed during tensile test conforms to set mass similar to St.Venant material. Initial tangent modulus, failure strain and creep strain of tensile stress-strain curves are optimum at resin: hardener ratio of two. High pressure triaxial test give cohesion value of  $450 \text{ kg/cm}^2$ .

#### GROUTED ROCK MASS

Considering the above time viscosity and strength behaviour the grout is selected for injection purpose consists of optimum ratio of resin: hardener two, along with five per cent dilution.

The rocks collected from various sites as mentioned earlier possess the following magasopic and microscopic characters:

- (A) (i) Porphyretic Basalt (collected from the site near Panam dam) - Minute fractures in horizontal direction and moderate weathering.
- (ii) Agglomerate Igneous (collected from the site near to Karjan dam) - trap, rock pieces are seen enclosed in the ground mass which is hetrogenous. Hetrogenity is more in horizontal direction, prominent fracturing, moderate weathering.
- (B) (i) Metamorphic, Criss-cross ion veinlets bearing (collected from construction site nearer to Chhuchapura) - bends are observed in horizontal direction, veinlets are noticed in horizontal direction, common fracturing and moderate weathering.
- (ii) Serpentine bearing metamorphic (collected from construction site nearer to Chhuchapura) - Greenish white bends observed in horizontal direction, while minute fracture seen in vertical direction, prominent fracturing and moderate weathering.

Samples of  $10\text{cm} \times 10\text{cm} \times 10\text{cm}$  with cut configuration at various orientation are produced and are placed in a square grouting box. Two drill holes from top surface of the above specimen are made upto the location cut to intersect maximum discontinuities. A suitable injection gun is developed for grouting (Fig.6).

A grouting operation is normally carried out to the lowest point to the highest. After filling the gun with epoxy grout, it is connected with tubing to an air compressor. A pressure of 4 to  $7 \text{ kg/cm}^2$  is used for the injection. A polyethylene nozzle of the gun is inserted into the drill hole of the rock specimen. Injection is continued till the resin begins to ozzes from the another drill hole. The process is continued until the cracks are completely sealed.

- 1.Brass top cover fixed with clamps.
- 2.Inlet for compressed air
- 3.Outlet
- 4.Compressed air
- 5.Polyethylene piston
- 6.Resin mix
- 7.Brass casing
- 8.High density polyethylene syring
- 9.Polyethylene nozzle.

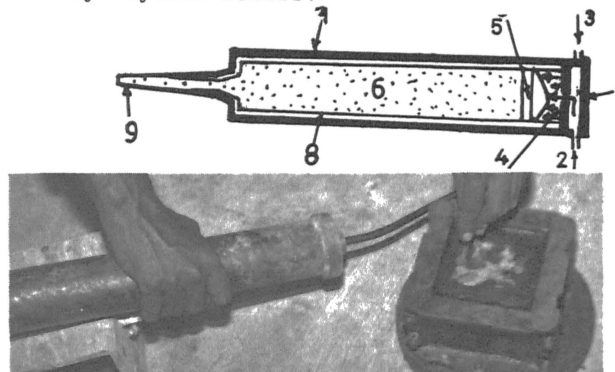


Fig. 6 Injection Gun.

#### STRENGTH OF GROUTED MASS

For these two groups of rock, adhesion over discontinuities and cracks by epoxy grout always exceed the strength of the rock (Fig.7).

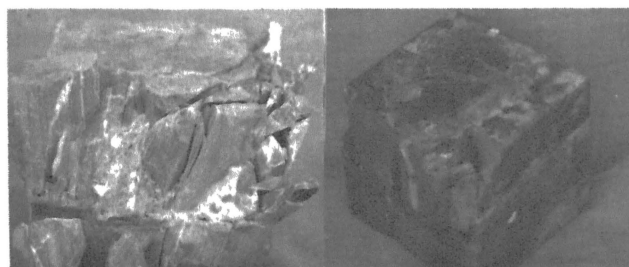


Fig.7 Rock specimen after failure.

Rupture always occurs through rock and never through the bonded crack surface. The strength of grouted rock specimens either in horizontal or vertical direction keeping the plane of cut perpendicular to the discontinuity, veinlets and structural hetrogeneity give compressive strength higher than intact rock. The test results on wet surfaces also show that significant strength could be developed across the discontinuities by bonding them with this epoxy resin grout (Fig.8 and 9).

After this laboratory grouting test, a trial injection was made with the above resin grout mix at the above mentioned sites. It is found that, it provides better bonds to moist rock and had more flexibility than other chemical grouts to accomodate movement before bond or shear failure occurred, and had shown lower volumetric shrinkage during curing. The strascopic inspection at the site have indicated that larger cracks and smaller cracks are appeared to be filled up and interacted properly with epoxy grout.

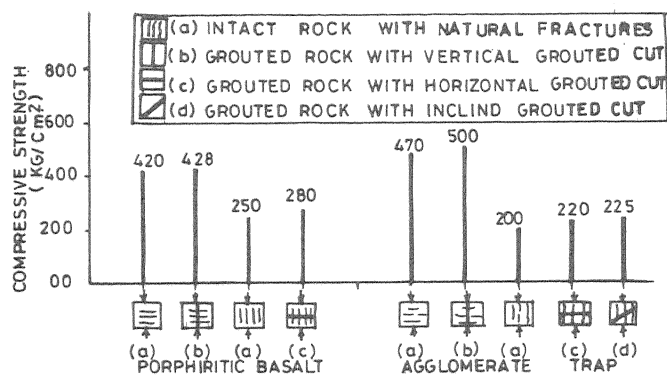


Fig.8 Compressive strength : Igneous rock.

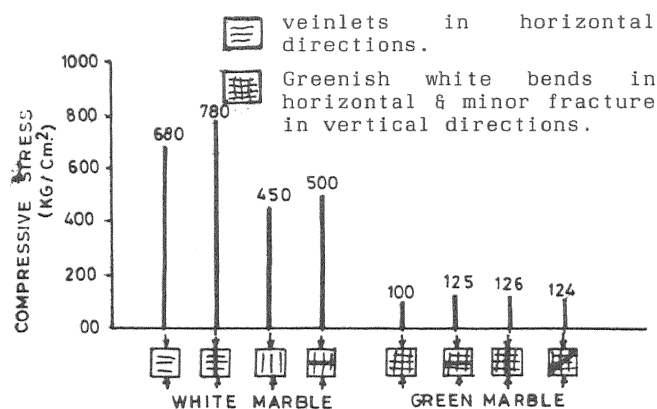


Fig.9 Compressive strength intact & grouted metamorphic rock.

## CONCLUSIONS

- (i) Epoxy grout system has controlled gellification time, insoluble gel in water, high gel strength, and high long term compressive and tensile strength.
- (ii) This grout system identifies following rheological changes during sol to gel : decrease of viscosity from original viscosity due to inherent temperature, increasing further to semi viscous, non-Newtonian converting suddenly to elasto-viscous gellified orange mass.
- (iii) Strength time relationship of set mass is strongly time dependent. For evaluation of deformation two categories basically identified : mainly time dependent linear elastic and time dependent non-linear elasto-plastic leading to brittle failure. Trace amount of water and resin hardener system makes the set mass elasto-plastic rather than brittle plastic exhibiting bulging at failure. During tensile strength stress strain behaviour conforms to St. Venant material.
- (iv) For igneous and metamorphic group of rocks, adhesion over discontinuities and cracks by epoxy grout always exceed the strength of the rock. Rupture always occurs through rock and never through bonded crack.
- (v) After trial field grouting, the stratascope study has revealed better bonds of

moist surface with flexibility to accommodate movement before bond or shear failure occurred alongwith lower volumetric shrinkage.

## ACKNOWLEDGEMENT

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